LASER IRRADIATION APPARATUS AND METHOD

REFERENCE TO RELATED APPLICATION

This is a Continuation-In-Part of International Application PCT/JP02/09928, filed September 26, 2002, which claims convention priority on Japanese Patent Application 2001-301713, filed September 28, 2001, both of which are incorporated by reference herein.

TECHNICAL FIELD

The present invention relates to laser irradiation apparatuses and laser irradiation methods for implementing laser irradiation and laser machining using a coherent beam.

BACKGROUND ART

A conventional laser machining apparatus is described with reference to Japanese Patent Laid-Open Application H8-2511. Fig. 9 illustrates a configuration of the conventional laser machining apparatus.

Laser beam 902A emitted from laser oscillator 901 maintains its parallelism by means of aspherical lenses 903 and 904. In addition, the Gaussian distribution of laser beam 902A with respect to its cross-section is converted to a uniform distribution. Uniform laser beam 902B is first horizontally focused by convex cylindrical lens 905, and then spread. Convex cylindrical lens 906, which has a longer focal length than that of lens 905, produces parallel laser beam 902C which is broadened more horizontally than laser beam 902B. Laser beam 902C enters light-focusing optical apparatus 908 via reflecting mirror 907. Laser beam 902C is then focused by each of plano-convex lenses 911 on light-focusing optical apparatus 908, and finally irradiates target workpiece 909 as several beam spots. Target workpiece 909 is moved using X-Y table 910 to apply necessary machining. The use of aspherical lenses

903 and 904 achieves uniformity of the intensity distribution of laser beam 902A, and allows laser beam 902A to be focused on the plano-convex lenses, and then beam 902A is irradiated on target workpiece 909 in multiple spots. This makes the laser energy density uniform on machining points 912, enabling uniform machining from the center to the periphery.

However, the above laser machining apparatus has the following disadvantage.

During laser machining, laser oscillation conditions are adjusted depending on the size and material of the target workpiece so as to achieve optimal machining conditions. In addition, in some cases, a pulse-oscillated laser beam is emitted to the same position on the target workpiece for several pulses. In this case, machining takes place while changing the laser oscillation conditions for every shot. A pointing vector of laser beam 902A emitted from laser oscillator 901 often changes as a result of changes in the oscillation conditions due to the thermal lens effect of an optical system inside a resonator. In particular, the pointing vector in an unstable resonator typically of a slab laser and a laser oscillator having many optical elements such as a wavelength-converting element inside or outside the resonator often actually changes when the oscillation conditions are changed. If the pointing vector changes due to variations in the oscillation conditions, as described above, a point of the laser beam entering lens 903 shifts. As a result, the uniformity of the intensity distribution of the laser beam exiting from lens 904 breaks down, causing variations in machining among multiple machining spots.

SUMMARY OF THE INVENTION

A laser irradiation apparatus of the present invention includes a light source for producing a coherent beam, a first optical unit disposed in the optical path between the light source and a target workpiece and a second optical unit disposed in the optical path between the first optical unit and the target workpiece. The first optical unit is disposed such that an entry point on the second optical unit and a starting point of a pointing vector of the beam from the light source are mutually conjugated with respect to the first optical unit.

Moreover, the laser irradiation apparatus of the present invention includes a light source for producing a coherent beam, a first optical unit disposed in the optical path between the light source and the target workpiece, a second optical unit disposed in the optical path between the first optical unit and the target workpiece and a third optical unit disposed in the optical path between the second optical unit and the target workpiece. The first optical unit focuses the coherent beam between the first and second optical units, and the second optical unit is disposed such that the focal point and the entry point on the third optical unit are mutually conjugated with respect to the second optical unit.

Further, in a laser irradiation method of the present invention, the coherent beam produced from the light source is irradiated to the target workpiece after being adjusted using the first optical unit and second optical unit. The first optical unit is disposed in the optical path between the light source and the target workpiece. The second optical unit is disposed in the optical path between the first optical unit and the target workpiece. The first optical unit is disposed such that the entry point on the second optical unit and the starting point of the pointing vector of the beam from the light source are mutually conjugated with respect to the first optical unit.

Furthermore, in the laser irradiation method of the present invention, the coherent beam produced from the light source is irradiated to the target workpiece after being adjusted using the first optical unit, second optical unit, and third optical unit. The first optical unit is disposed in the optical path between the light source and the target workpiece. The second optical unit is disposed in the optical path between the first optical unit and the target workpiece. The third optical unit is disposed in the optical path between the second optical unit and the target workpiece. The first optical unit focuses the coherent beam between the first optical unit and second optical unit. The second optical unit is disposed such that its focal point and the entry point on the third optical unit are mutually conjugated with respect to the second optical unit.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view of a laser machining apparatus in accordance with a first exemplary embodiment of the present invention.

Figs. 2A and 2B are graphical representations of the intensity distribution of a laser beam in accordance with the first exemplary embodiment of the present invention.

Fig. 3 illustrates a configuration and function of an optical transmission system for the laser beam in accordance with the first exemplary embodiment of the present invention.

Fig. 4 illustrates behavior of the laser beam in a conventional configuration.

Fig. 5 is a graphical representation of the intensity distribution of a laser beam at the position of a phase-matching element in the conventional configuration.

Fig. 6 is a schematic view of a laser machining apparatus in accordance with a second exemplary embodiment of the present invention.

Fig. 7 illustrates a configuration and function of an optical transmission system for the laser beam in accordance with the second exemplary embodiment of the present invention.

Fig. 8 illustrates behavior of the laser beam in the conventional configuration.

Fig. 9 is a schematic view of a conventional laser machining apparatus.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIRST EXEMPLARY EMBODIMENT

Fig. 1 is a schematic view of a laser machining apparatus in a first exemplary embodiment of the present invention.

CO_2 laser beam 12A in TEM00 mode, emitted from CO_2 laser oscillator (hereafter referred to as 'oscillator') 11, enters intensity-converting element 14 while optical transmission system 13 adjusts the beam radius to the most appropriate radius for intensity-converting element 14. The intensity distribution of laser beam 12A transmitted through intensity-converting element 14 is changed from a Gaussian distribution to a uniform

distribution at phase-matching element 15. The wave surface of laser beam 12A transmitted through phase-matching element 15 becomes planar or spherical without any distortion.

Fig. 2A shows the Gaussian intensity distribution of laser beam 12A on the entry face of intensity-converting element 14. Fig. 2B shows the uniform intensity distribution of laser beam 12A on the exit face of phase-matching element 15.

Laser beam 12A transmitted through phase-matching element 15 further passes through scaling projection optical system 16, and enters mask 17. Scaling projection optical system 16 projects an image at the position of phase-matching element 15 to the position of mask 17. In other words, the position of phase-matching element 15 and the position of mask 17 are conjugated with respect to scaling projection optical system 16. Laser beam 12A, which has a uniform intensity distribution and uniform phase distribution at the position of phase-matching element 15, will lose its uniformity as laser beam 12A spreads, but its intensity distribution becomes uniform again at the position of mask 17, being projected by scaling projection optical system 16. The phase distribution also becomes uniform at mask 17. The projection magnification of scaling projection optical system 16 is variable so that the intensity distribution area of the laser beam on mask 17 is adjustable to the optimal size based on the size of mask 17.

Next, projection lens 18 projects laser beam 12A from an opening of mask 17 to target workpiece 19. Since the positions of mask 17 and target workpiece 19 are conjugated with respect to projection lens 18, the intensity of laser beam 12A is uniformly distributed on target workpiece 19. Since the size of mask 17 is variable, the intensity distribution area of laser beam 12A on target workpiece 19, given by the multiple of the size of mask 17 and projection lens 18, is changed as required. Optical transmission system 13, intensity-converting element 14, phase-matching element 15, scaling projection optical system 16, mask 17, and projection lens 18 are disposed on the optical axis of laser beam 12A without positional deviation or inclination.

Next, the function of optical transmission system 13 is detailed. Laser beam 12A produced from oscillator 11 often changes its pointing vector by changes in oscillation conditions, typically due to the thermal lens effect of an optical system inside oscillator 11.

In the case of laser machining in this exemplary embodiment, the laser oscillation conditions are optimized for machining depending on the target workpiece type. In addition, when multiple shots are applied to the same workpiece for machining, the pulse width or repeating frequency is changed depending on the number of shots in some cases.

Fig. 3 illustrates the case when the pointing vector of the laser beam is shifted.

In this Figure, the pointing vector shifts to form a profile of laser beam 12B. Here, starting point 31 of the pointing vector of laser beam 12A and the exit face of intensity-converting element 14 are mutually conjugated with respect to optical transmission system 13. In other words, optical transmission system 13 is disposed such that the image at the starting point of the pointing vector of laser beam 12A is projected on the exit face of intensity-converting element 14. The configuration of optical transmission system 13 at this position enables the laser beam to always enter at the center of intensity-converting element 14 even though the pointing vector of the laser beam shifts, such as to laser beam 12B.

Fig. 4 shows an example of the prior art in which optical transmission system 113 is disposed such that starting point 131 of the pointing vector and the exit face of intensity-converting element 114 are not conjugated. In this case, laser beam 112B does not enter at the center of intensity converting element 114. If the entry point of the laser beam is out of the center of intensity-converting element 114, and this configuration is applied to the laser machining apparatus shown in Fig. 1, the uniform intensity distribution on the exit face of phase-matching element 15 degrades, as shown in Fig. 5.

Accordingly, in this exemplary embodiment, optical transmission system 13 is disposed such that an image at starting point 31 of the pointing vector of laser beam 12A is projected on intensity-converting element 14. This allows the laser beam always to enter at the center of intensity-converting element 14 even if the pointing vector of the laser beam shifts, such as to laser beam 12B, enabling the laser beam distribution to always be converted to a uniform intensity distribution.

SECOND EXEMPLARY EMBODIMENT

Fig. 6 is a schematic view of a laser machining apparatus in a second exemplary embodiment of the present invention.

CO_2 laser beam 602A in TEM00 mode, emitted from CO_2 laser oscillator (hereafter referred to as 'oscillator') 601, enters intensity-converting element 605 while light-focusing optical system 603 and optical transmission system 604 adjust the beam radius. The intensity distribution of laser beam 602A transmitted through intensity-converting element 605 is changed from a Gaussian distribution to a uniform distribution at the position of phase-matching element 606. The wave surface of laser beam 602A transmitted through phase-matching element 606 becomes planar or spherical.

The Gaussian distribution of laser beam 602A on the entry face of intensity-converting element 605 and uniform distribution of laser beam 602A on the exit face of phase-matching element 606 are the same as those shown in Figs. 2A and 2B in the first exemplary embodiment.

Laser beam 602A transmitted through phase-matching element 606 further passes through scaling projection optical system 607, and enters mask 608. Scaling projection optical system 607 projects an image at the position of phase-matching element 606 on the position of mask 608. In other words, the position of phase-matching element 606 and the position of mask 608 are conjugated with respect to scaling projection optical system 607. Laser beam 602A, which has a uniform intensity distribution and uniform phase distribution at the position of phase-matching element 606, will lose its uniformity as laser beam 602A spreads, but its intensity distribution becomes uniform again at the position of mask 608, being projected by scaling projection optical system 607. The phase distribution also becomes uniform at mask 608. The projection magnification of scaling projection optical system 607 is variable so that the intensity distribution area of the laser beam on mask 608 is adjustable to the optimal size based on the size of mask 608.

Next, projection lens 609 projects laser beam 602A from an opening of mask 608 on target workpiece 610. Since the positions of mask 608 and target workpiece 610 are conjugated with respect to projection lens 609, the intensity of laser beam 602A is uniformly

distributed on target workpiece 610. Since the size of mask 608 is variable, the intensity distribution area of laser beam 602A on target workpiece 610, given by the multiple of the size of mask 608 and projection lens 608, is changed as required. Light-focusing optical system 603, optical transmission system 604, intensity-converting element 605, phase-matching element 606, scaling projection optical system 607, mask 608, and projection lens 609 are disposed on the optical axis of laser beam 602A without positional deviation or inclination.

Next, the function of light-focusing optical system 603 and optical transmission system 604 is detailed. Laser beam 602A produced from oscillator 601 often changes its pointing vector by changes in oscillation conditions, typically due to the thermal lens effect of an optical system inside oscillator 601. In the case of laser machining in this exemplary embodiment, the laser oscillation conditions are optimized for machining depending on the target workpiece type. In addition, when multiple shots are applied to the same workpiece for machining, the pulse width or repeating frequency is changed depending on the number of shots in some cases.

Fig. 7 shows the case when the pointing vector of laser beam 602A is shifted.

Laser beam 602B adopts the state shown in the Figure due to shifting of the pointing vector. Light-focusing optical system 603 converges laser beam 602A or laser beam 602B between light-focusing optical system 603 and optical transmission system 604. Optical transmission system 604 projects the laser beam at this focal point 611 on the exit face of intensity converting element 605. In other words, focal point 611 and the exit face of intensity-converting element 605 are conjugated with respect to optical transmission system 604. The projection magnification of the optical system consisting of light-focusing optical system 603 is determined such as to achieve a predetermined beam radius for the laser beam entering intensity-converting element 605.

As shown in Fig. 7, when the starting point of the pointing vector of the laser beam is at an infinite point with respect to the laser oscillator, the pointing vector shifts in parallel. In this case, the use of light-focusing optical system 603 and optical transmission system 604 in this exemplary embodiment makes the laser beam enter at the center of intensity-

converting element 605 even though the pointing vector of the laser beam is shifted in parallel.

Fig. 8 is an example of the prior art when focal point 711 and the exit face of intensity-converting element 705 are not conjugated with respect to optical transmission system 704. In this case, laser beam 702B does not enter at the center of intensity-converting element 705. When the entry point of the laser beam entering intensity-converting element 705 is shifted from the center of the intensity-converting element, and this configuration is applied to the laser machining apparatus shown in Fig. 6, the uniform intensity distribution on the exit face of phase-matching element 606 degrades, which is the same as in Fig. 5 in the explanation of the first exemplary embodiment. Accordingly, in the second exemplary embodiment, light-focusing optical system 603 and optical transmission system 604 are employed for focusing laser beam 602A between light-focusing optical system 603 and optical transmission system 604, and optical transmission system 604 projects the laser beam at this focal point 611 on the exit face of intensity-converting element 605. This allows the laser beam always to enter at the center of intensity-converting element 605 even if the pointing vector of the laser beam shifts, such as to laser beam 602B, enabling to the laser beam distribution to be converted to a uniform intensity distribution.

The laser beam described in the exemplary embodiments is a CO_2 laser beam. However, the present invention is also applicable to other beams suitable for use in machining such as YAG laser and He-Ne laser beams.

The laser irradiation apparatuses which convert the laser beam distribution to a uniform intensity distribution and implement laser irradiation for machining can achieve a continuing high quality of machining with one of the configurations as below, even if the pointing vector of the laser beam shifts:

A) An optical transmission system is disposed such that the entry point of an intensity-converting element and the starting point of a pointing vector of a laser beam are mutually conjugated with respect to the optical transmission system.

B) A light-focusing optical system converges a coherent beam between the light-focusing optical system and an optical transmission system. The optical transmission system is

disposed such that the focal point of the optical transmission system and the entry point of an intensity converting element are mutually conjugated with respect to the optical transmission system.